Brazilian team

# Problem 05
# Car


reporter:

Bárbara Cruvinel Santiago

# Problem 05
# Car

Build a model car powered by an engine using an elastic air-filled toy-balloon as the energy source. Determine how the distance travelled by the car depends on relevant parameters and maximize the efficiency of the car.

# Contents

# Introduction: Definitions

- Car: any object which moves over wheels without getting off of the floor or overturning, just using an internal independent source (air inside the balloon).

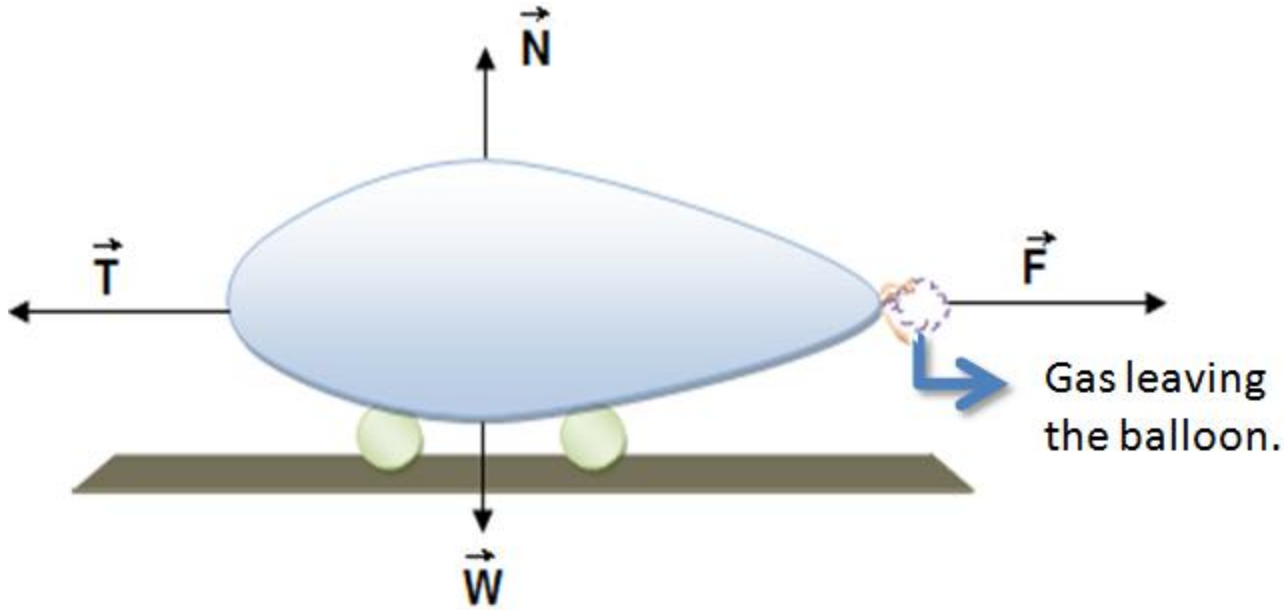
- Efficiency: ratio between useful energy and internal energy.

$$\eta = \frac{E_{out}}{E_{in}}$$

- Vehicle Autonomy: distance per amount of air (combustible) – used as an indicator of efficiency.

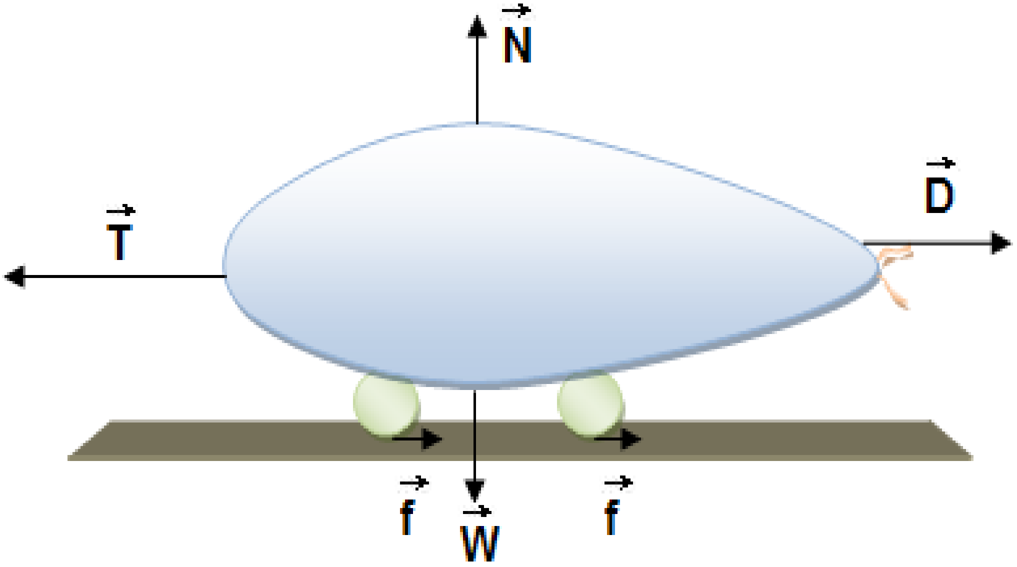
# Introduction: Forces acting over the car

- Gas force:



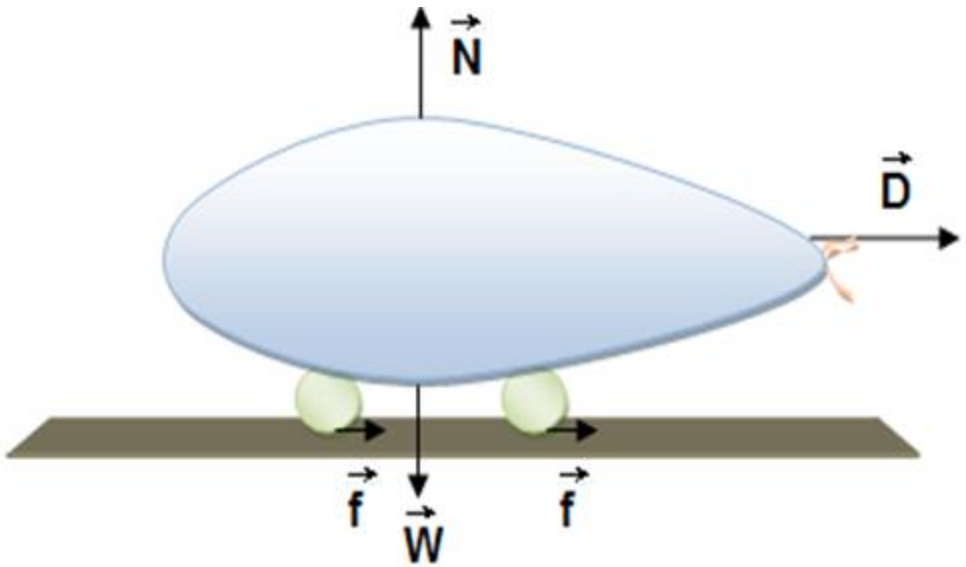
# Introduction: Forces acting over the car

- Since then:



# Introduction: Forces acting over the car

- After the gas end:



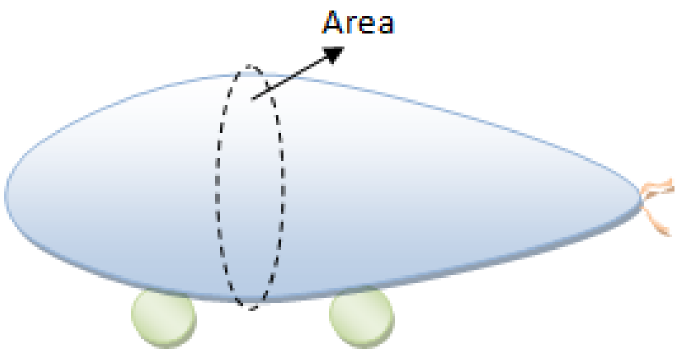
# Introduction: Gas propulsion force

- Variable force:
  - Mass;
  - Volume;
  - Moles;
  - Internal pressure.
- Influence of temperature and type of gas (saw in Clapeyron's equation):

$$PV = \frac{m}{M} RT$$

# Introduction: Drag Force

$$D = \frac{1}{2}\rho C_x A v^2$$




- **Humidity:** alters the air density (almost irrelevant)

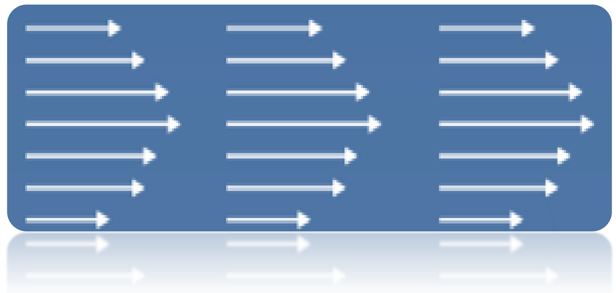
# Introduction: Friction

There is no propulsion torque → Tendency of sliding in the direction of the motion → Friction contrary to the motion

- We do not know if the friction is dynamic or static, as it would depend on the propulsion force.

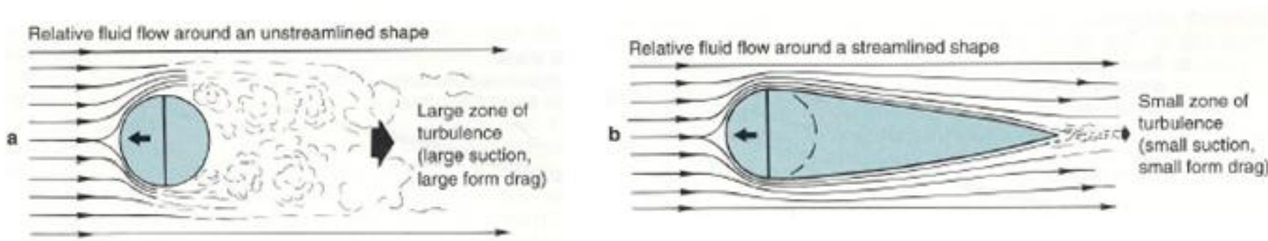
# Introduction: Flow

- Laminar:

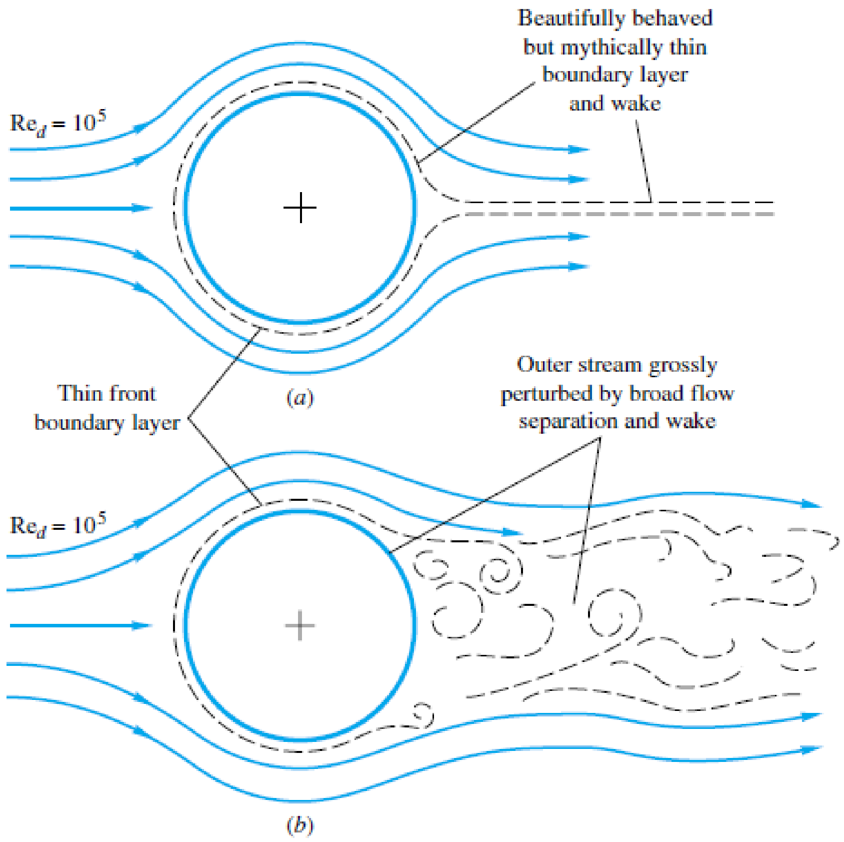


- Turbulent:

- Laminar is better:



# Introduction: Flow




(a) theory

(b) real

- The boundary layer breaks because of the pressure gradient.

# Introduction: Rolling

- In order to improve the rolling, it is better to decrease the rolling between wheels and axis.

# Introduction: Balloon elasticity

- Hooke's Law:

$$F = kx$$

→ Applicable to a narrow strip of the balloon.

Stiffer balloon → Higher internal pressure → Higher propulsion force

- There's a limit number of times to use the same balloon, as it loses the stiffness.

# Experiment: Experimental description

- **Experiment 1:** aerodynamics test.
- **Experiment 2:** nozzle test.
- **Experiment 3:** propeller test.
- **Experiment 4:** chassis test.
- **Experiment 5:** surface test.
- **Experiment 6:** elasticity test.
- **Build the car based on the found parameters.**
  - Constant volume inside the balloon, as we pumped an air pump 70 times.
  - Inaccuracies: precision of the measuring tape (±0.05cm), of the caliper rule (±0.05mm) and of the scale (±0.1g).

# Experiment: Material

- Geometric solids (cardboard and Styrofoam)
- Plastic wheels
- Slot car
- Wind tunnel (cardboard and fan)
- Digital chronometer
- Measuring tape
- Hair dryer
- Nozzles of different shapes (cardboard)

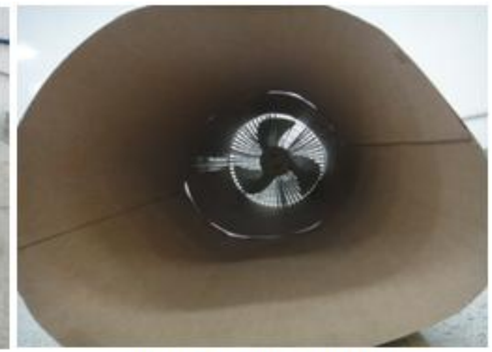
# Experiment: Material

- Caliper rule with precision of 0.05mm
- Paper (to make a straw)
- Air pump
- Elastic toy-balloon
- Corrugated fiberboard
- Adhesive tape
- Marbles
- String
- Scale with a precision of 0.1g

# Experiment: Experiment 1 - aerodynamics test

- **Aerodynamics**
- Nozzle
- Propeller
- Chassis
- Surface
- Elasticity
- Car building

Tunnel from the outside



Tunnel from the inside

Droplet

Sphere

Cylinder

Cone

Cube

Parallelepiped

Pyramid

# Experiment: Experiment 1 - aerodynamics test

- Aerodynamics
- Nozzle
- Propeller
- Chassis
- Surface
- Elasticity
- Car building

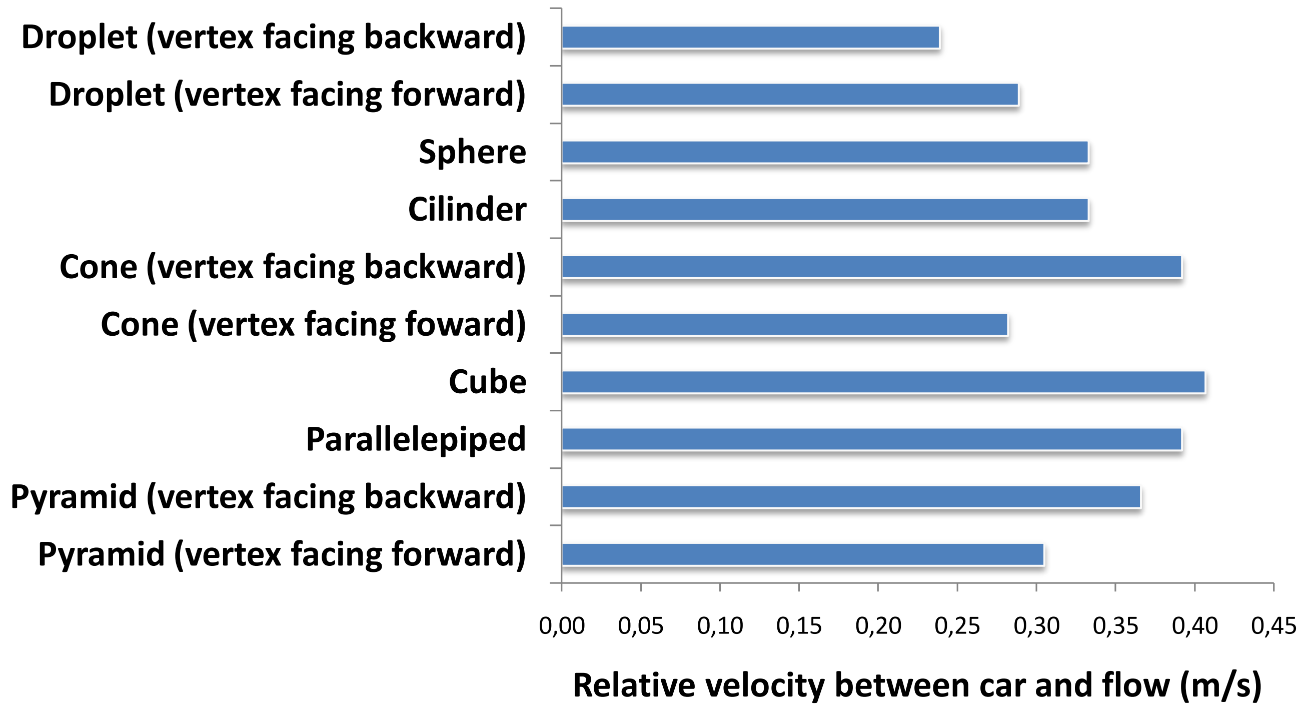
## Theoretical drag coefficients

| | | | | | |
|---|---|---|---|---|---|
| | Droplet | < 0.1 | | Truck | 0.8-1.0 |
| | Sport car | 0.2-0.3 | | Bike with cyclist | 0.9 |
| | Semi-sphere (opened backwards) | 0.38 | | Cube | 1.05 |
| | Passenger car | 0.4-0.5 | | Flat plate | 1.2 |
| | Sphere | 0.47 | | Motorcycle with a person | 1.8 |
| | Bus | 0.6-0.8 | | Semi-sphere (opened forwards) | 1.42 |
| | Cylinder | 0.7-1.3 | | Section in C (opened forwards) | 2.30 |

# Experiment: Experiment 1 - aerodynamics test

- Aerodynamics
- Nozzle
- Propeller
- Chassis
- Surface
- Elasticity
- Car building

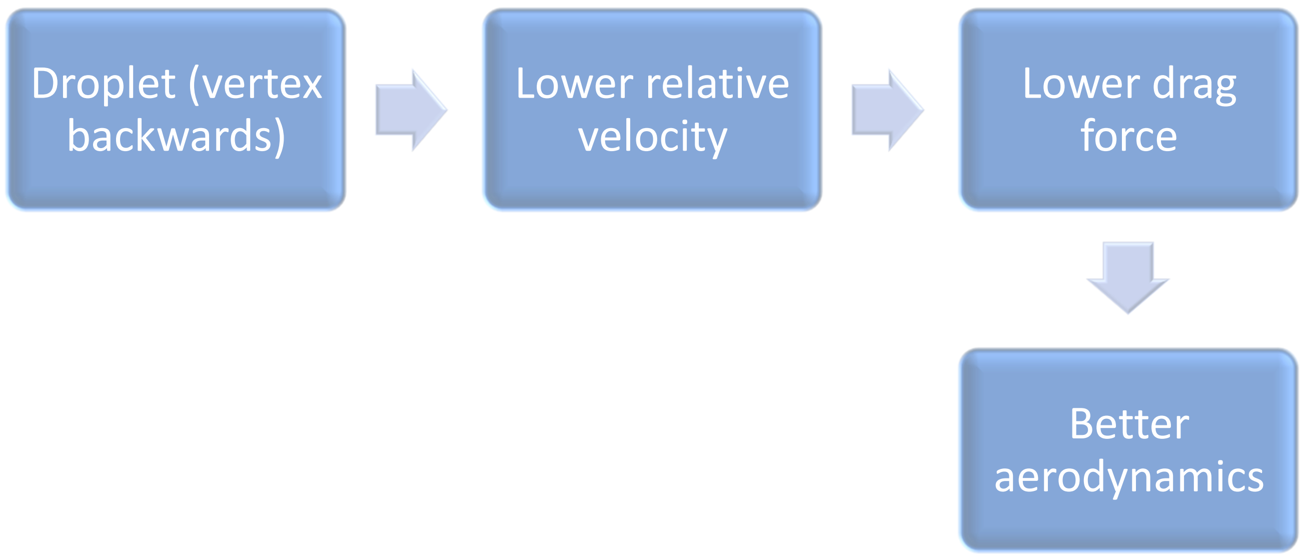
## Relative velocity between car and flow




- Possible error: lag time due to chronometer use(≅0.4s).

# Experiment: Experiment 1 - aerodynamics test

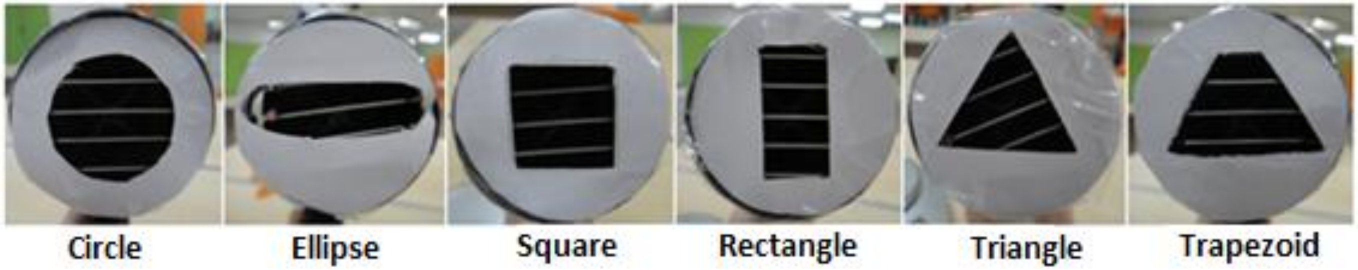
- Aerodynamics
- Nozzle
- Propeller
- Chassis
- Surface
- Elasticity
- Car building




- The experimental data agrees with theoretical coefficients.

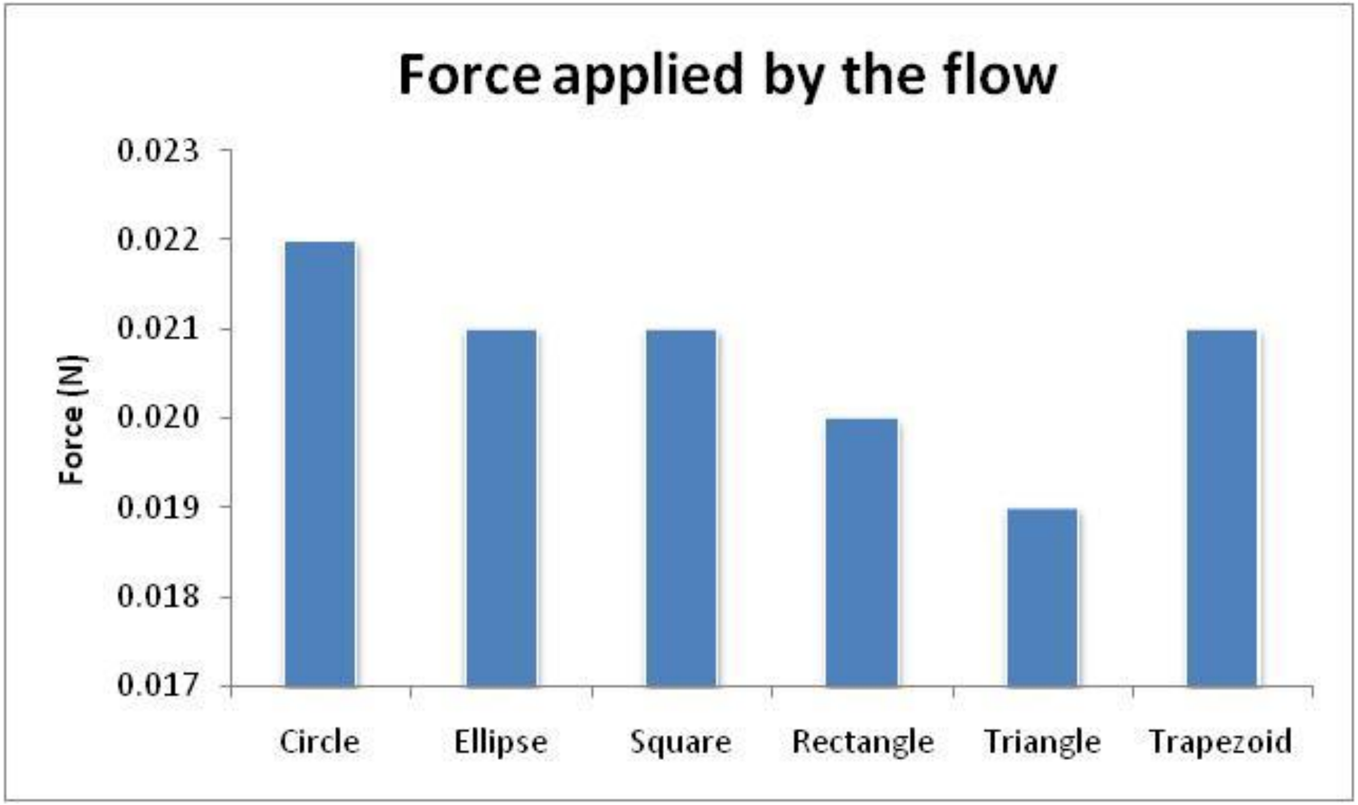
# Experiment: Experiment 2 - nozzle test

- Aerodynamics
- Nozzle
- Propeller
- Chassis
- Surface
- Elasticity
- Car building



# Experiment: Experiment 2 - nozzle test

- Aerodynamics
- Nozzle
- Propeller
- Chassis
- Surface
- Elasticity
- Car building



# Experiment: Experiment 2 - nozzle test

- Aerodynamics
- **Nozzle**
- Propeller
- Chassis
- Surface
- Elasticity
- Car building

Circular nozzle → Less regional turbulence → Better shape for nozzle

# Experiment: Experiment 3 - propeller test

- Aerodynamics
- Nozzle
- **Propeller**
- Chassis
- Surface
- Elasticity
- Car building

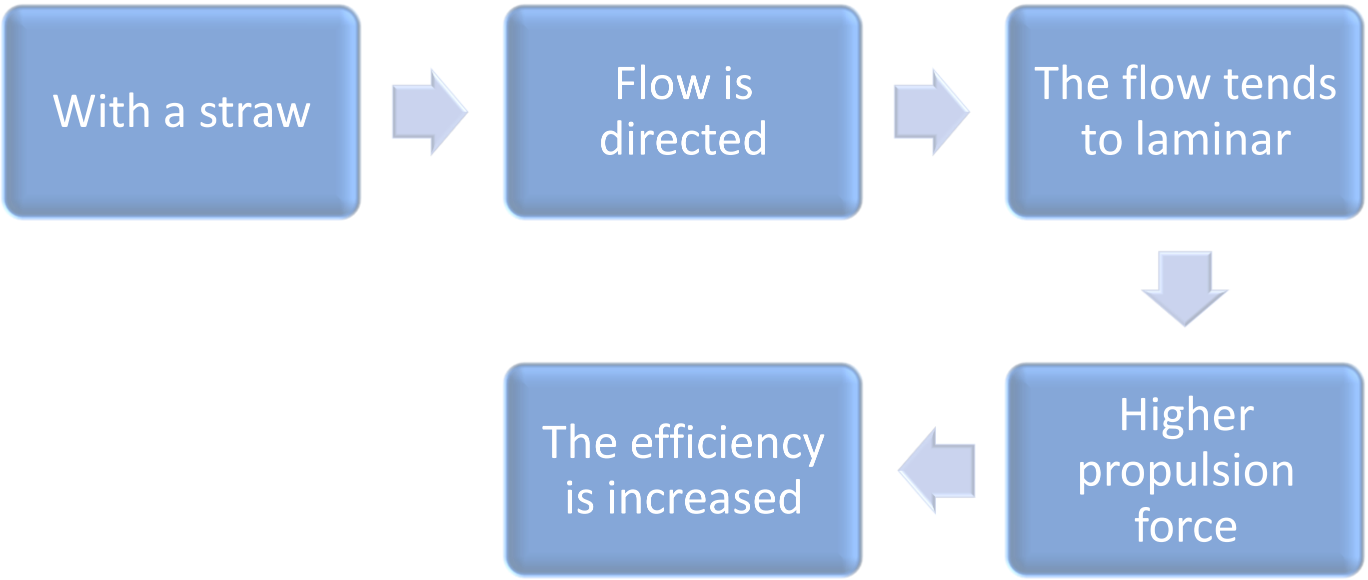
Without a straw

With a straw

| | Traveled distance for different propellers (m) | |
|---|---|---|
| | **Without a straw** | **With a straw** |
| **1st** | 2.49 | 3.38 |
| **2nd** | 2.12 | 4.05 |
| **3rd** | 2.02 | 3.15 |
| **Average** | **2.21** | **3.53** |
| **Standard deviation** | 0.25 | 0.47 |

# Experiment: Experiment 3 - propeller test

- Aerodynamics
- Nozzle
- Propeller
- Chassis
- Surface
- Elasticity
- Car building



# Experiment: Experiment 4 - chassis test

- Aerodynamics
- Nozzle
- Propeller
- Chassis
- Surface
- Elasticity
- Car building

Test track

Chassis used in the experiments

Tested cars

# Experiment: Experiment 4 - chassis test

- Aerodynamics
- Nozzle
- Propeller
- Chassis
- Surface
- Elasticity
- Car building

| | Traveled distance for different chassis (m) | |
|---|---|---|
| | **Parallelepiped** | **Wedge** |
| **1st** | 2.39 | 0.41 |
| **2nd** | 1.89 | 0.35 |
| **3rd** | 2.01 | 0.39 |
| **Average** | **2.10** | **0.38** |
| **Standard deviation** | 0.26 | 0.03 |

- Even the wedge shape being more aerodynamic, its wheels showed to be worst, because of the friction.

# Experiment: Experiment 5 - surface test

- Aerodynamics
- Nozzle
- Propeller
- Chassis
- **Surface**
- Elasticity
- Car building

Floor with slots

More uniform surface

| | Traveled distance for different surfaces (m) | |
|---|---|---|
| | **With slots on the floor** | **More uniform** |
| **1st** | 2.39 | 2.49 |
| **2nd** | 1.89 | 2.12 |
| **3rd** | 2.01 | 2.02 |
| **Average** | **2.10** | **2.21** |
| **Standard deviation** | 0.26 | 0.25 |

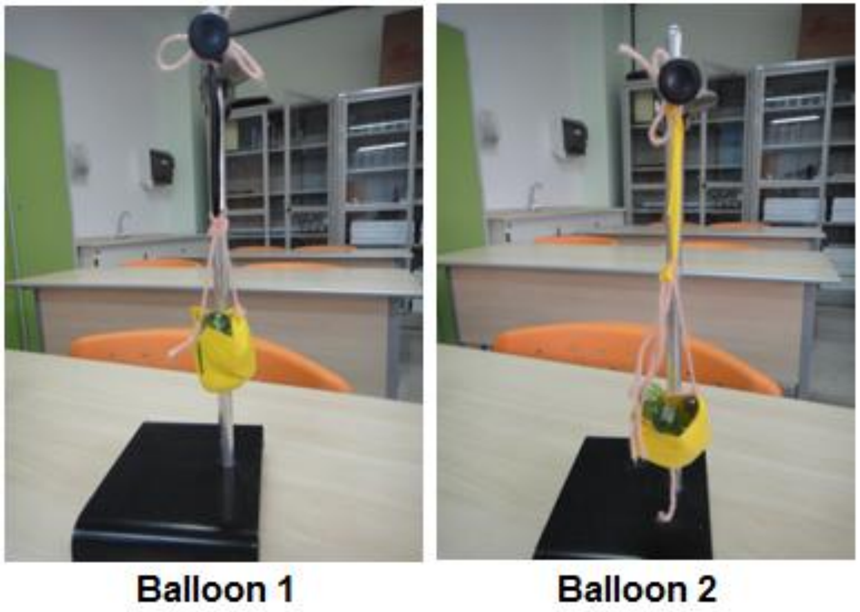
# Experiment: Experiment 5 - surface test

- Aerodynamics
- Nozzle
- Propeller
- Chassis
- **Surface**
- Elasticity
- Car building

More uniform surface → Less friction → Maximize the vehicle autonomy (and the efficiency)

# Experiment: Experiment 6 - elasticity test

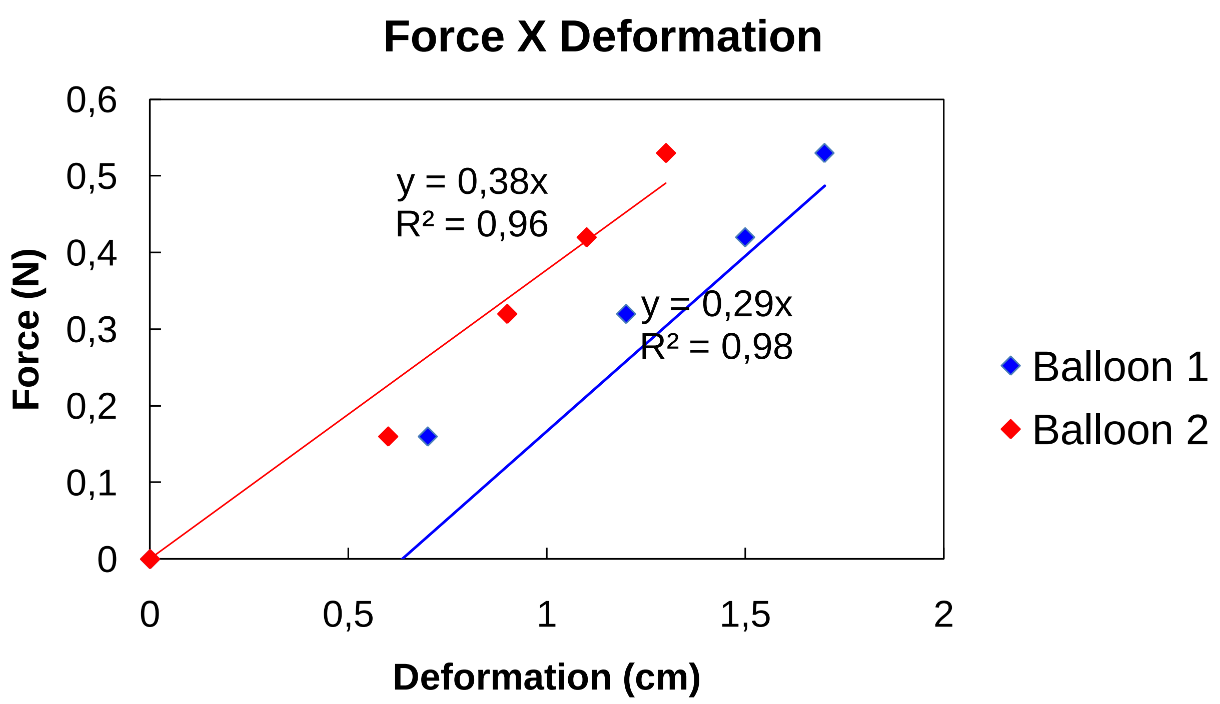
- Aerodynamics
- Nozzle
- Propeller
- Chassis
- Surface
- Elasticity
- Car building




- Balloon 1: k = 0.29N/cm
- Balloon 2: k = 0.38N/cm

# Experiment: Experiment 6 - elasticity test

- Aerodynamics
- Nozzle
- Propeller
- Chassis
- Surface
- **Elasticity**
- Car building



# Experiment: Experiment 6 - elasticity test

- Aerodynamics
- Nozzle
- Propeller
- Chassis
- Surface
- Elasticity
- Car building

Balloon 1

Balloon 2

**Maximum number of times that the same balloon can be used with similar results (vary maximum of 30cm):**

- Balloon 1: 2 times.
- Balloon 2: 3 times.

# Experiment: Experiment 6 - elasticity test

- Aerodynamics
- Nozzle
- Propeller
- Chassis
- Surface
- Elasticity
- Car building

| | Traveled distance for different elasticities (m) | |
|---|---|---|
| | **Balloon 1 (k=0.29)** | **Balloon 2 (k=0.38)** |
| **1st** | 2.49 | 2.06 |
| **2nd** | 2.12 | 2.11 |
| **3rd** | 2.02 | 1.89 |
| **Average** | **2.21** | **2.02** |
| **Standard deviation** | 0.25 | 0.12 |

# Experiment: Experiment 6 - elasticity test

- Aerodynamics
- Nozzle
- Propeller
- Chassis
- Surface
- **Elasticity**
- Car building

Stiffness should be increased → Aerodynamics was worse for the stiffer → Both cars showed basically the same efficiency

# Experiment: Car building

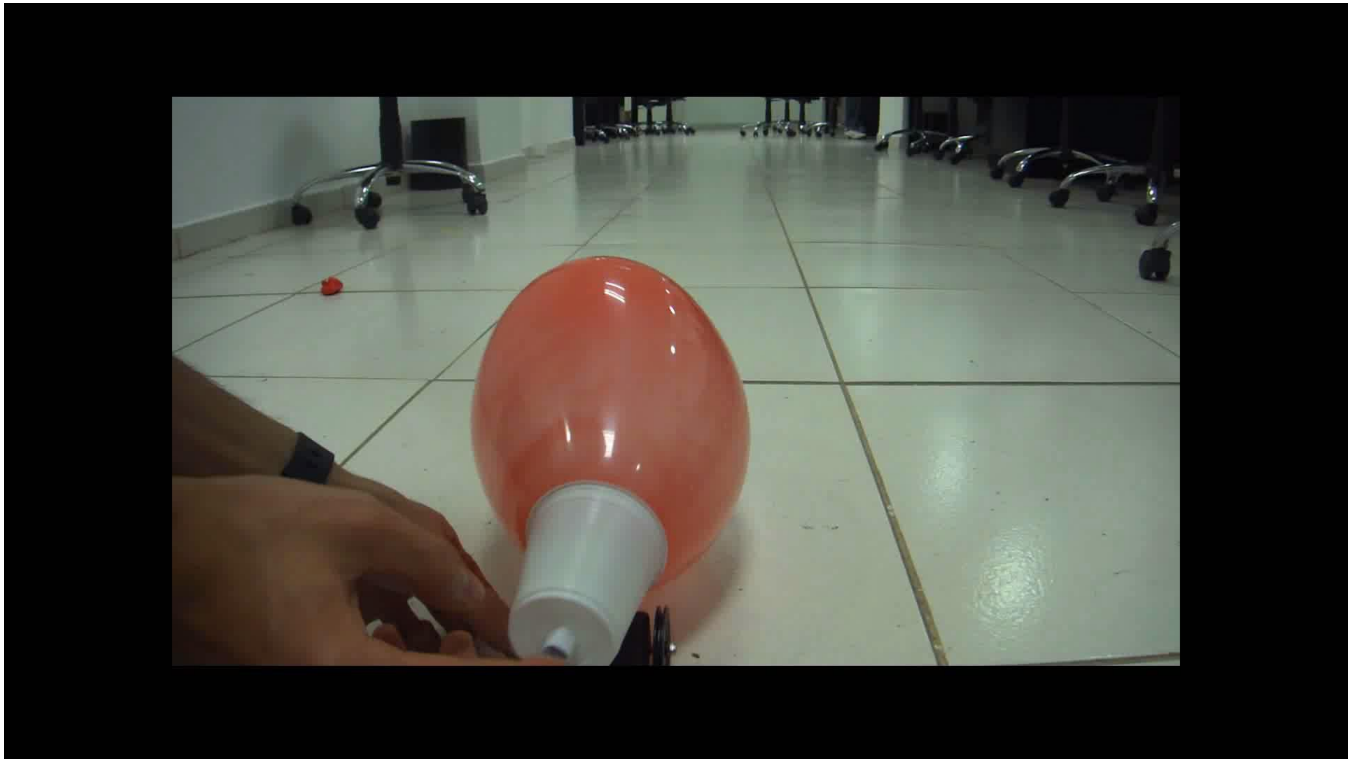
- Aerodynamics
- Nozzle
- Propeller
- Chassis
- Surface
- Elasticity
- Car building

- Shape: droplet
- Nozzle: circular
- Chassis: plastic wheels in a parallelepiped chassis
- Propeller: with a straw

Built car

# Experiment: Built car video

- Aerodynamics
- Nozzle
- Propeller
- Chassis
- Surface
- Elasticity
- **Car building**



# Conclusion

- Most relevant parameters for the efficiency:
  - Increase the driving force (gas propulsion);
  - Decrease the resisting forces;
  - Use the found relevant parameters to get this.
- Features for the built car:
  - Droplet shape (experiment 1);
  - Circular nozzle (experiment 2);
  - Paper straw as propeller (experiment 3);
  - Wheels with less friction (experiment 4);

# References


- 1.http://dic.busca.uol.com.br/result.html?t=10&ref=homeuol&ad=on&q=carro&group=0
- 2. http://dic.busca.uol.com.br/result.html?t=10&ref=homeuol&ad=on&q=efici%
- EAncia&group=0
- 3. FOGO, Ronaldo; FIGUEIREDO, Eduardo – **Apostila Objetivo 1ª série do Ensino Médio 3º Bimestre** – Ed. Cered – São Paulo – 2010
- 4. WHITE, Frank M. – **Fluid Mechanics** – WCB McGrall-Hill
- 5. SALLES, Antônio Mário – **Apostila Objetivo 1ª série do Ensino Médio 4º Bimestre** – Ed. Cered – São Paulo – 2010
- 6. http://www.portalsaofrancisco.com.br/alfa/resistencia-do-ar/resistencia-do-ar.php
- 7. **GRUPO DE REELABORAÇÃO DO ENSINO DE FÍSICA –** Leituras de física (mecânica) – Editor da Universidade de São Paulo – São Paulo – 1998
- 8. http://www.algosobre.com.br/fisica/aerodinamica.html
- 9. Hallyday/Resnick/Walker – **Fundamentos de Física – Volume 1 – Mecânica** – Rio de Janeiro – 2008
- 10. JUNIOR, Prof. Dr. Guanis de Barros Vilela – **Dinâmica dos fluidos**
- 11. http://en.wikipedia.org/wiki/Hooke%27s_law
- 12. Hallyday/Resnick/Walker – **Fundamentos de Física – Volume 2 – Gravitação, Ondas e Termodinâmica** – Rio de Janeiro – 2011
- 13. http://en.wikipedia.org/wiki/Energy_conversion_efficiency
- 14. http://www.grc.nasa.gov/WWW/K-12/airplane/thrust1.html
- 15. http://revistaescola.abril.com.br/ensino-medio/pratica-golfe-rende-boa-licao-mecanica-fluidos-425767.shtml
- 16. http://www.if.ufrj.br/teaching/fis2/hidrodinamica/viscosidade.html

# Acknowledgements

- B8 Projetos
- Universidade Paulista – UNIP
- Escola Politécnica da Universidade de São Paulo
- Colégio Mater Amabilis
- Colégio Objetivo
- Instituto Dom Barreto
- Universidade Federal do Piauí
- Victor Ando
- César Freire
- Gilberto Júnior Jacob

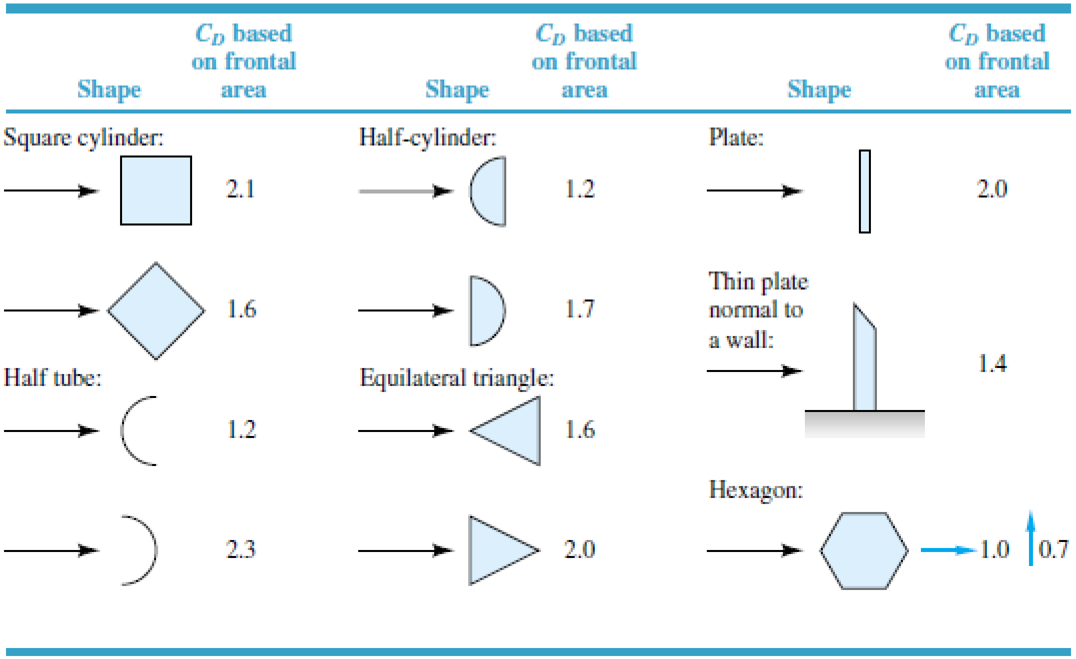
# Reynolds Number

$$Re = \frac{\rho v D}{\mu}$$

Re = Reynolds Number (dimensionless)
ρ = fluid density (S.I.: $Kg/m^3$)
D = diameter of the tube (S.I.: m)
μ = dynamic viscosity of the fluid (S.I.: Pa.s)

- Re<2100: laminar flow
- Re>4000: turbulent flow

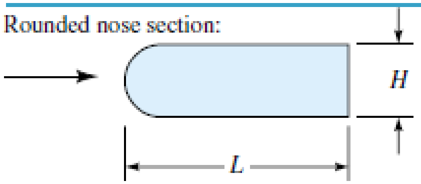
# Drag coefficient for different shapes



# Drag coefficient for different shapes

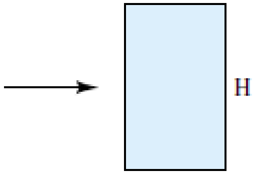
| Shape | $C_D$ based on frontal area |
|---|---|

Rounded nose section:



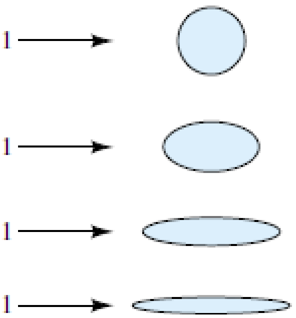

| $L/H$: | 0.5 | 1.0 | 2.0 | 4.0 | 6.0 |
|---|---|---|---|---|---|
| $C_D$: | 1.16 | 0.90 | 0.70 | 0.68 | 0.64 |

Flat nose section



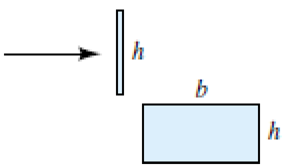
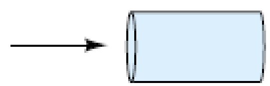

| $L/H$: | 0.1 | 0.4 | 0.7 | 1.2 | 2.0 | 2.5 | 3.0 | 6.0 |
|---|---|---|---|---|---|---|---|---|
| $C_D$: | 1.9 | 2.3 | 2.7 | 2.1 | 1.8 | 1.4 | 1.3 | 0.9 |

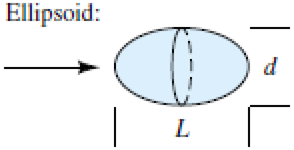
Elliptical cylinder:



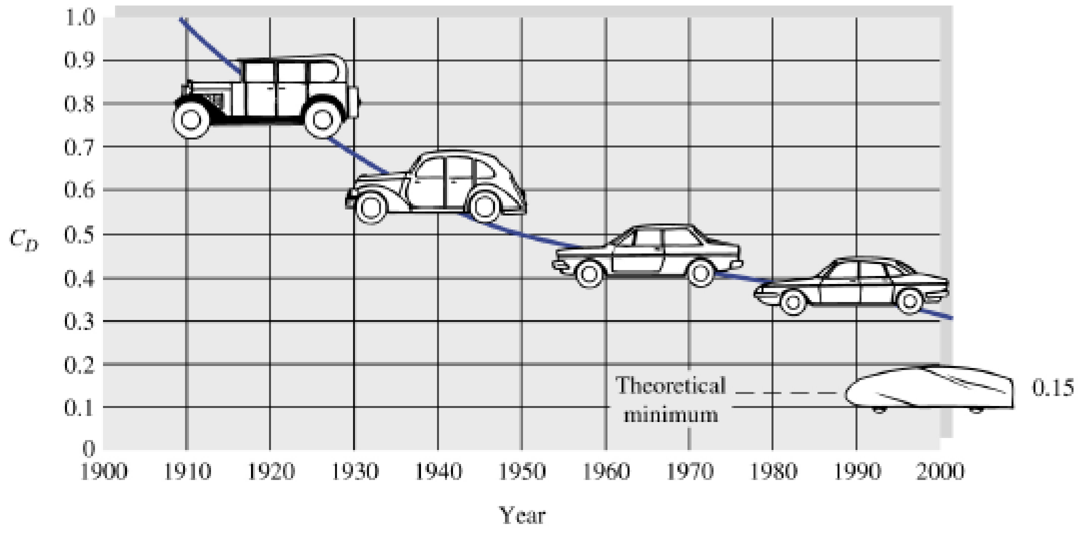
| | Laminar | Turbulent |
|---|---|---|
| 1:1 | 1.2 | 0.3 |
| 2:1 | 0.6 | 0.2 |
| 4:1 | 0.35 | 0.15 |
| 8:1 | 0.25 | 0.1 |

# Drag coefficient for different shapes

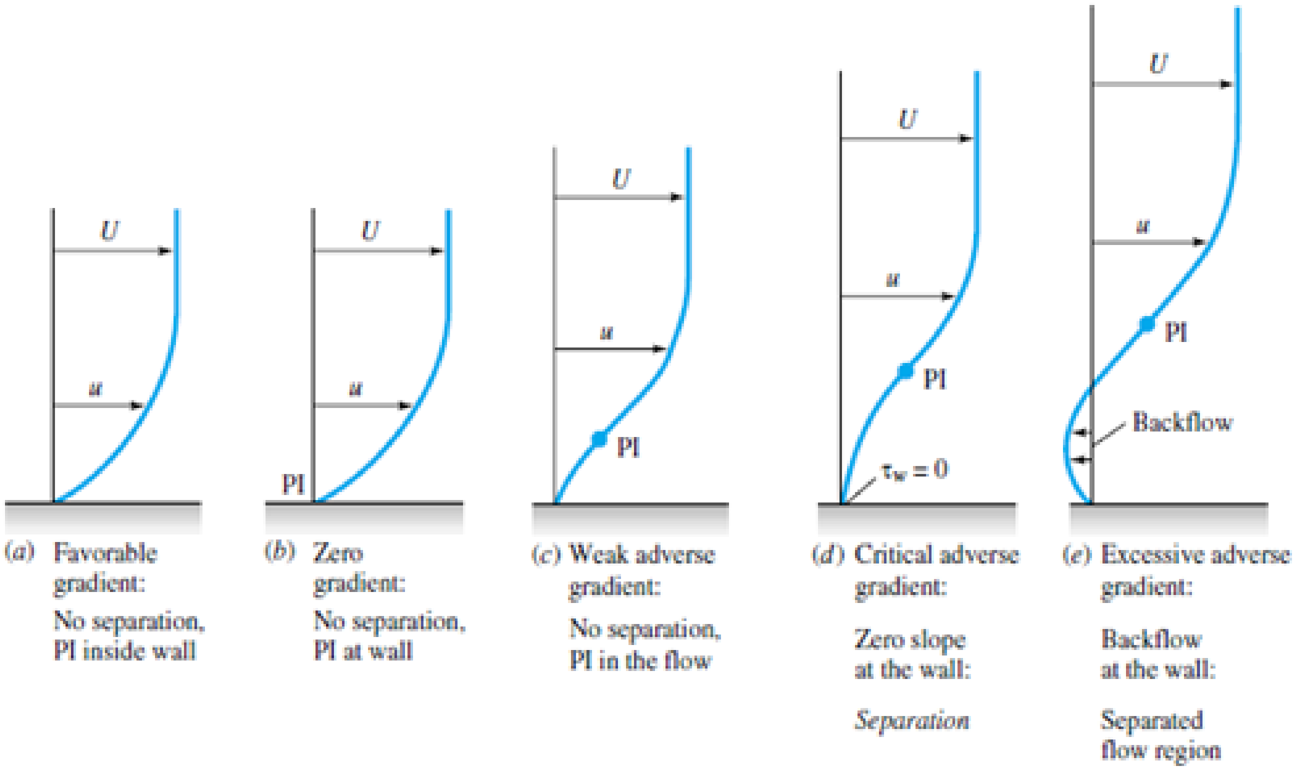
| Body | Ratio | $C_D$ based on frontal area | Body | Ratio | $C_D$ based on frontal area |
|---|---|---|---|---|---|
| Rectangular plate: | | | Flat-faced cylinder: | | |
|   | *b/h* 1 | 1.18 |  | *L/d* 0.5 | 1.15 |
| | 5 | 1.2 | | 1 | 0.90 |
| | 10 | 1.3 | | 2 | 0.85 |
| | 20 | 1.5 | | 4 | 0.87 |
| | ∞ | 2.0 | | 8 | 0.99 |

| Body | Ratio | Laminar | Turbulent |
|---|---|---|---|
| Ellipsoid: | | | |
|   | *L/d* 0.75 | 0.5 | 0.2 |
| | 1 | 0.47 | 0.2 |
| | 2 | 0.27 | 0.13 |
| | 4 | 0.25 | 0.1 |
| | 8 | 0.2 | 0.08 |

# Drag coefficient for different shapes

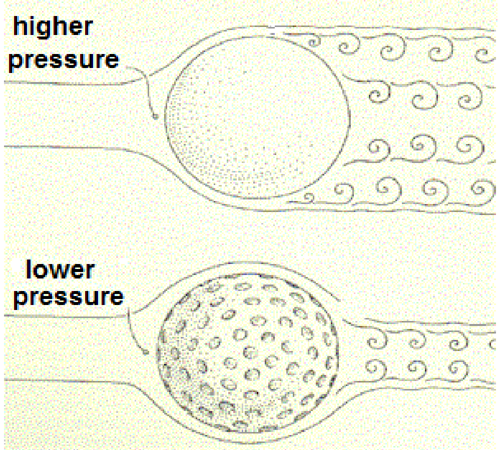


# Pressure gradient (boundary layer breaks)



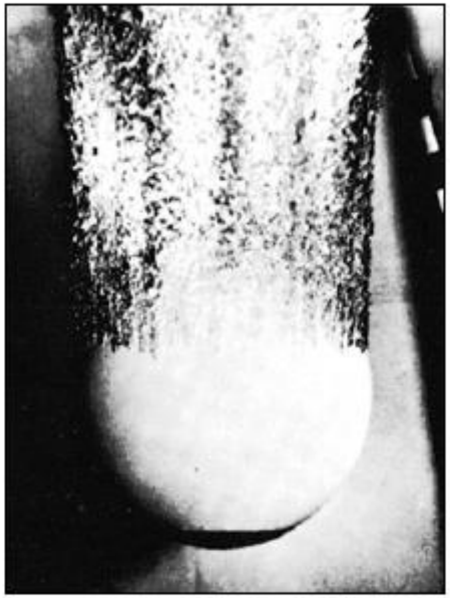
# Golf ball case

- Turbulent flow is better:
  - Reduces the partial vacuum in the backside (existent with laminar flow);
  - Reattaches the boundary layer to the ball's surface;
  - Drag force due to pressure is eliminated (just have the viscosity drag acting);
  - The rugosity induces the turbulent flow.



# Golf ball case

Laminar flow



Induced turbulent flow

# Engine

- Definition (Oxford Dictionary): “the part of a vehicle that produces power to make the vehicle move”.
- Observation: it doesn’t need to have mobile parts.
- Example: ramjet (use the air pressure for combustion and expulsion).